



Alpine vegetation composition, structure, and soils monitoring for Rocky Mountain National Park

2010 Summary Report

Natural Resource Data Series NPS/ROMN/NRDS—2011/148



ON THE COVER

Katharine Driver, Isabel Ashton on a GLORIA sentinel site (PIK) measuring a 10 x 10 m plot and a 1 x 1 m plot. The Never Summer Mountains are in the background, July 2010, Rocky Mountain National Park. Photograph by: Brittany Thompson

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Executive Summary

Alpine ecosystems are important monitoring targets for the Rocky Mountain Inventory and Monitoring Network (ROMN) for a number of reasons, including their value to park visitors, wildlife, and water resources in the West. Alpine ecosystems are also particularly vulnerable to climate change. Here, we present a summary of our efforts in 2010 to monitor vegetation composition, structure, and soils at four sentinel sites in the alpine of Rocky Mountain National Park (ROMO). This was not a full monitoring event; instead we spent time piloting new methods and adding confidence to our species lists. This report is intended to provide a timely release of basic data sets and data summaries. We expect to produce reports with more in-depth data analysis and interpretation when we do the second full sample event (5 years) or as needed for park management and interpretation. We found the following:

- We found between 63-71 vascular plant species on each of the four summits. The lowest summit is smaller in area than the other three summits and has a higher diversity per area. We found 8 new species in 2010 that were not recorded during 2009 GLORIA sampling.
- The optional method of 100 m² plots took about 2 hours per plot for 2 researchers. In areas with low plant diversity (typically the rocky western slopes), 1 m² plots sufficiently estimated diversity and cover. However, 100 m² plots did increase our detection of species in more heterogeneous areas with high vascular plant cover.
- Soil chemistry and texture was similar across all four summits and aspects in the GLORIA target region. We found soil texture to be a sandy clay loam at all peaks. Soil pH and carbon to nitrogen ratios were similar to values documented in alpine of the Front Range.
- Soil temperature loggers have been deployed in 16 locations since 2008. The 2010 growing season in the alpine (as defined by above freezing temperatures) began in the last few days of May at all four sites which was about 10 days later than in 2009.

Continued monitoring of the vegetation and temperature at sentinel sites will allow us to determine whether climate change correlates with changes in biodiversity in select locations in ROMO's alpine. Warmer temperatures may contribute to the extinction of some plant species while simultaneously increasing the elevation and latitudinal limitations of other species.

Acknowledgments

I thank all those that assisted with field work: Katharine Driver, Kurt Chowanski. Kyle Motley, Brittany Thompson, Clinton Whitten, Laura O’Gan and Paul McLaughlin. I would also like to thank the staff at ROMO for being exceptionally helpful with logistics, housing, and accommodating our office needs particularly Cheri Yost and Judy Visty. We also thank the CSU Plant and Soils Laboratory for analyzing our soil samples. Finally, the staff at the GLORIA office have been invaluable, particularly Barbara Friedmann and Christian Klettner, by providing databases, field sheets, and methods. This manuscript was improved by comments from Bernadette Kuhn, Judy Visty, and the ROMN staff.

Introduction

One of the objectives of the National Park Service (NPS) Inventory & Monitoring (I&M) Program is to develop and provide scientifically credible information on the current status and long-term trends of the composition, structure, and function of park ecosystems, and to determine how well current management practices are sustaining those ecosystems. The Rocky Mountain I&M Network (ROMN) identified vegetation composition, structure, and soils as a vital sign that can be used to better understand the condition of terrestrial park ecosystems (Britten et al. 2007). The alpine, defined as the vegetation communities that exist above treeline, is represented in three of the ROMN parks: Glacier National Park, Rocky Mountain National Park (ROMO) and Great Sand Dunes National Park. The area above treeline including vegetated and non-vegetated areas makes up 28%, 20%, and 3% land cover in each park, respectively. The ROMN selected alpine ecosystems as an important vegetation monitoring target in these parks for a number of reasons, including their value to park visitors, wildlife, and water resources in the West. The alpine is also an important monitoring target because it is particularly vulnerable to climate change.

The long-term objectives of our alpine monitoring effort are to:

- (1) Determine the status and trend in **vegetation composition and structure** of four sentinel alpine peak communities at a range of elevations.
- (2) Determine status and trend in **cover of invasive/exotic plant species** at four sentinel alpine peak communities at a range of elevations.
- (3) Determine the status and trend in **soil condition** based on a suite of physical and chemical properties that include: surface stability, soil carbon (C) and nitrogen (N) content, pH, texture, evidence of erosion, extent of bare (non-vegetated) soils, and compaction at four sentinel alpine peak communities.
- (4) Determine the status and trend in **soil temperature** and snow cover period of four sentinel alpine peak communities at a range of elevations.

A summary of our initial effort to monitor vegetation composition, structure, and soils in the alpine of ROMO in 2009 can be found in Ashton et al. (2010a). We plan to complete a full resurvey and monitoring effort at of these sites in 2014. Here, we present a summary of our efforts in 2010. In 2010, our goal was to pilot new methods in the GLORIA protocol and to resurvey a select number of plots to estimate annual variation in plant communities. This report is intended to provide a timely release of basic data sets and data summaries. We expect to produce reports with more in-depth data analysis and interpretation when we do the second full sample event (5 years) or as needed for park management and interpretation.

Methods

The ROMN adapted an alpine monitoring protocol from the Global Observation Research Initiative in Alpine Environments (GLORIA), an international monitoring network established in 2001 to assess and predict biodiversity and temperature changes in alpine communities in response to drivers such as climate (Pauli et al. 2004). The GLORIA program is operated through the University of Vienna and more information can be found at their website (<http://www.gloria.ac.at/>). The goals of the GLORIA program are to provide a global baseline for vegetation monitoring in alpine environments and to assess the risks of biodiversity loss and ecosystem instability from climate change. The methodology is extended by cooperators, such as the ROMN, to create a long-term monitoring network at the global scale. The ROMN Alpine Vegetation Composition, Structure, and Soils monitoring protocol follows those established by GLORIA but adds components for soil condition, treeline movement, and human disturbances (Ashton et al. 2010b).

Sample design

We followed the GLORIA monitoring design (Grabherr et al. 2000), which for one GLORIA site calls for the establishment of four sentinel sites on alpine peaks representing an elevation gradient within a target region (e.g. Rocky Mountain National Park, CO). The sites are established on the top of the peaks (summits) and the summits vary from just above treeline to the highest life zones of vegetation. Within one region, all four summits share qualitatively similar geology, climate, disturbance, and land-use history leaving vegetation differences among the summits to be driven primarily by elevation. The four alpine monitoring sentinel sites within ROMO are listed in Table 1.

Table 1. Name, location, elevation, and vegetation zone of the four alpine sentinel sites within the target region of ROMO.

GLORIA Summit code	Summit name	Latitude (decimal degrees)	Longitude (decimal degrees)	Elevation (m)	Vegetation zone
GLA	Shoulder of Mount Ida	40.380617	-105.770072	3862	upper alpine
PIK	Unnamed	40.392956	-105.790538	3715	lower/upper alpine
VQS	Unnamed	40.406275	-105.799238	3623	lower alpine
JSM	Jackstraw	40.394304	-105.813083	3520	lower alpine/subalpine ecotone

Plot layout and sampling

Eight summit area sections are used to measure the exact dimensions of the peak (area and slope) from the highest point to 10 m in elevation below the summit. Steeper summits have smaller areas than flatter summits. Summit sections are used to measure the coarse-scale ground cover of the peaks. To measure ground cover, seven cover classes are employed: solid rock, scree, vascular plants, lichens, bryophytes, bare ground, and litter. Researchers walk the entire area and keep a running checklist of plant species and a rough estimate of abundance. This method is used because it gives the best estimate of summit species diversity (Pauli et al. 2004). In 2010, we completed summit area surveys on VQS and PIK and completed 5 of 8 sections on JSM. Completing all summit area surveys on a peak required approximately 6 hours for 2 or more field persons (a full field day in the alpine).

To measure vegetation change, a series of nested plots are placed within each summit. The core sampling effort is conducted in quadrat clusters, one placed on the north, east, south, and west side of the peak each which contain 9-1 m^2 quadrats (Figure 2, 3). The four quadrats in the corner of each quadrat cluster are used to measure plant cover (16 quadrats per peak). Cover is measured by ocular estimates of vascular plant species and coarse cover class (lichen, bryophyte, plants, litter, soil, rock, scree). In 2010, we measured cover in 16 1m^2 plots on JSM, VQS, and PIK. Bad weather prohibited us from surveying plant vegetation at the highest peak: GLA. Recording species cover in the 1m^2 quadrats took approximately 4-6 hours per peak (a full field day) for 1 person. The 1m^2 quadrats can also be used to record the presence and frequency of plants in 100 $10 \times 10\text{m}$ cells and of herbivore damage including trampling, scat, and browsing. This frequency sampling was not done in 2010 because it is very time consuming. A daily record of sampling is contained in Appendix 1 and a detail of the data collected can be found in Table 2.

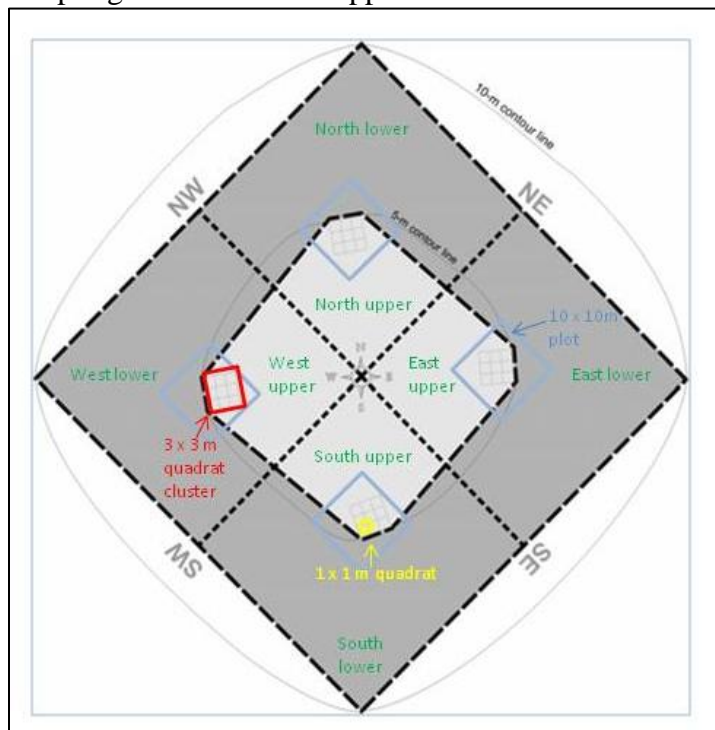


Figure 1. Field plot design for alpine monitoring where this design was replicated on four summits that varied in elevation. The design is centered by the highest point on the summit and extends to 10 m in elevation below the highest point. The 1m^2 quadrats used to measure changes in plant frequency are indicated in yellow.

Four larger plots are used to estimate diversity and cover at the scale of 100m^2 using line intercept methods. A $10\text{m} \times 10\text{m}$ plot is outlined and 20 10m transects are run through the plot (Figure 2). A pin is dropped every 0.5m and each species the pin hits is recorded. This is an optional method in the GLORIA Manual and was developed for peaks with low vegetation cover. We piloted this method in 2010 at two of our peaks- VQS and PIK. The time to complete a 100m^2 plot varied between 1 and 2.5 hours. Plots with higher plant cover and graminoids dominance in particular, required at least 2 hours to complete.

Soil temperature is measured hourly at a depth of 15cm in 4 locations on all peaks using HOBO Onset Dataloggers. The dataloggers are placed in the center of each quadrat cluster. The

dataloggers were originally installed in the fall of 2008 and have been replaced annually in the summer. In 2010, we replaced all loggers in July. The loggers have the memory and battery power to be deployed for longer than one year, but replacing them is relatively quick and ensures that we can report on soil temperature data in a timely manner. Our strategy has been to replace the loggers each year, rather than download the data in the field and continue to use the same logger. This is done because it eliminates the need for a computer in the field. Also, we are then able to check if all the dataloggers are working and properly programmed prior to deploying them.

Table 2. Types of plots present on each GLORIA summit and data available for analyses. Each quadrat cluster contains 9 quadrats but only 4 are used for vegetation surveys. No vegetation surveys were done at GLA in 2010. A dash indicates data were not taken in 2010.

Plot type	Size	Number of plots per peak	2010 JSM Sampling effort	2010 VQS Sampling effort	2010 PIK Sampling effort	Available Data
Summit	Variable; extending from 0 to 10m below highest point	1	-	-	-	Natural and Anthropogenic disturbance
Summit Area	Variable; extending from 0-5m and 5-10m below highest point for each direction	8	5 (upper N, E, S,W, lower S)	8	8	Species presence; Cover class
Plot	100 m ²	4	-	4	2 (E and W)	Species frequency
Quadrat cluster	9 m ²	4	4	4	4	Hourly Soil Temperature; Soil parameters
Quadrat	1 m ²	16	16 (cover)	16 (cover)	16 (cover)	Cover class; Species cover; Species frequency; Frequency of herbivore damage

In 2009, soil chemistry was estimated at each peak by collecting a soil sample from each of the quadrat clusters. Soils were sampled to a depth of 20cm at three locations using a 2cm diameter soil probe. The three samples per quadrat were combined in a plastic bag and brought back to the office. The soil samples were air dried and sent to a cooperating laboratory at Colorado State University for analysis. Data was not available at the time of publication for the 2009 report, so it is included here. The soil samples taken in 2009 will provide a baseline for the GLORIA sites and we plan to repeat collections every 5 or 10 years. Our expectation is that soils will respond more slowly than vegetation to change.

In total, the field work in 2010 took 10 days. Two days were spent at the lowest peak JSM. The first day, July 4, was used to replace dataloggers and take photographs that were missed in 2009 by I. Ashton and K. Chowanski. The second day included 5 people (but only 2 botanists) and was used to monitor vegetation in 1 m² plots and summit area sections. Five days were spent sampling vegetation at VQS and this was done primarily by K. Driver, I. Ashton, and K. Motley. Finally, 2 days were spent at PIK. The dataloggers at GLA were replaced on one day by K. Chowanski and K. Driver. GLA, VQS, and PIK were sampled as day trips from Milner Pass and

JSM was sampled as day trips from Lake Irene. For 8 of the 9 days, afternoon storms required us to stop sampling at 1:30pm or earlier.

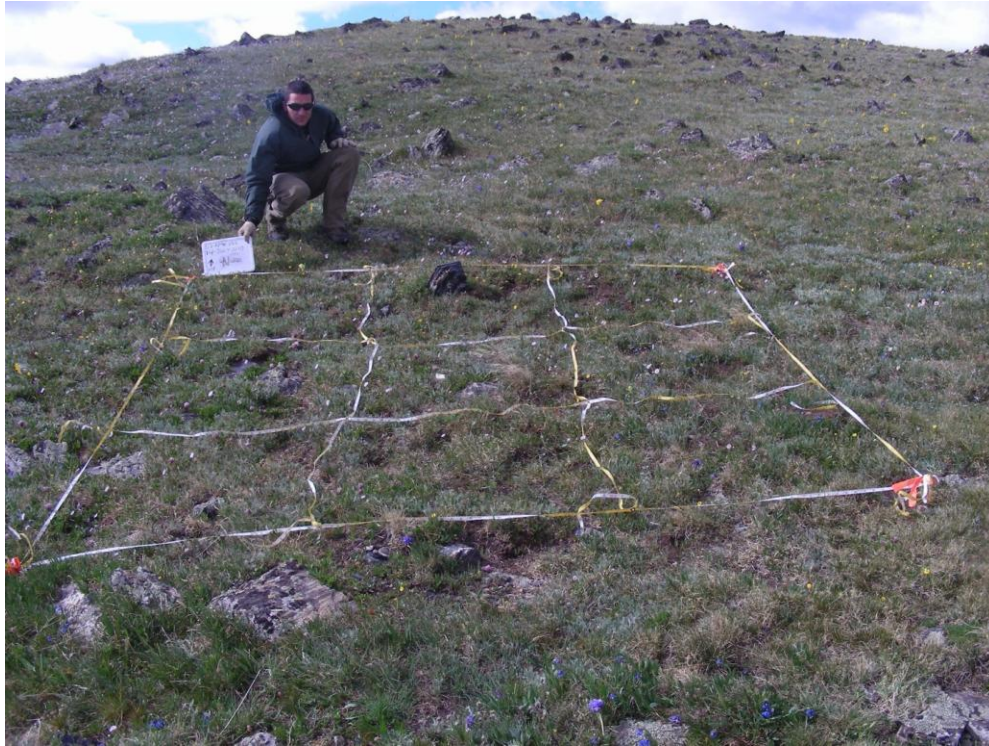


Figure 2. Clinton Whitten on the VQS GLORIA peak at Rocky Mountain National Park. A divided meter tape outlines a 9 m² quadrat cluster on the east side of the peak. (July, 2010; photograph by Kurt Chowanski).

After field sampling, species lists were compiled, and any new species found in 2010 were sent to the GLORIA offices, and fit to an international standard of nomenclature used by all GLORIA sites. The GLORIA office then delivered to ROMN species definitions to be used in the data-entry database for the RMN target region. Rather than using a new database for 2010 (as will be done in the next full monitoring cycle) these data were considered an addendum to the 2009 database and all 2010 data were added as if for a new peak (JS1, PK1, and VQ1). This was done at the recommendation of the GLORIA office. Photographs taken in 2010 were added to the 2009 photograph tracking database and included a large number of species identification pictures. We estimate the data entry process took 40 hours with 20 hours spent on proper documentation of photographs and species. The QA/QC process, which is mainly automated, is completed and both the photograph database and GLORIA database are available to the park upon request. Both databases are on the shared ROMN drive in the alpine monitoring database folder. The GLORIA office at the University of Vienna also has copies (<http://www.gloria.ac.at/>).

The main purpose of this report is to provide an annual update of the data and metadata collected in the alpine at ROMO in 2010. As a result, we conducted very few statistical analyses and instead present simple descriptive statistics. Soil data were analyzed in R 2.9.2 (2009) using a multivariate model (manova) to test for differences among summits. Plant species lists from each

summit were linked to C scores derived from a list for all vascular plants in Colorado (Rocchio 2007). C scores were assigned to plants on the premise that plants of high conservation value (high C score taxa) are not able to adapt to human induced alterations and are typically the first plants to disappear from a habitat impacted by human activities (Wilhelm 1996, Lopez and Fennessy 2002). Non-conservative species tend to dominate habitats that have had been exposed to prolonged and/or severe human impacts, resulting in a loss of ecological complexity.

Results

Vegetation Composition and Structure

In 2010, we added 9 new species to the regional list. The new species were: *Anemone narcissiflora* var. *zephyr*, *Campanula uniflora*, *Carex microptera*, *Dryas octopetala* ssp. *hookeriana*, *Ranunculus eschscholtzii*, *Carex arapahoensis*, *Helictotrichon mortonianum*, *Arnica rydbergii*, and *Taraxacum officinale* ssp. *ceratophorum*. Many of these species were seen for the first time in 2010, while others were likely lumped into other similar species in 2009 and correctly identified in 2010. For instance, *D. octopetala* was seen for the first time in 2010, but *Carex arapahoensis* was likely misidentified in 2009 as *C. scopulorum*.

All four summits have similar species richness (Table 3) with an average of 66 ± 1.9 vascular plants species found in the summit area. The species list from summit surveys in 2010 is included in Appendix 2. There was not a strong gradient in species richness by summit or elevation except when area is considered. Because JSM is the smallest in area it has the highest species density. The mean C score of the native vascular plants across summits is 7.1 ± 0.19 with the higher summits tending to have higher C scores (Table 3). *Taraxacum officinale* was the only non-native species found in the region and this was seen on the lowest summit, JSM. Tree and shrub species were also most prevalent on the lowest summit.

Table 3. The summit area, number of species present, mean C score of native species, non-native species richness, and the richness of tree and shrub species on four alpine sentinel sites as measured in 2009 and 2010. Asterisks indicate data collected in 2009.

GLORIA Summit code	Elevation (m)	Summit Area (ha)	Number of vascular plant species	Mean C score of native species	Non-native species richness	Tree and shrub species richness
GLA*	3862	0.51	65	7.5	0	1
PIK	3715	0.59	63	7.2	0	3
VQS	3623	0.78	71	7.1	0	0
JSM*	3520	0.24	63	6.6	1	5

In most cases, we found more species in 2010 than in 2009 in the summit area surveys (Table 4). In 8 of the 37 sections resurveyed, we found a difference of larger than 20% between years. The boundaries defining summit sections are not marked (they are found based on a bearing and distance) and slight variation in placement between years may explain some of the variation in the species lists. We also had more botanists in the field in 2010.

In the 100m² plots on PIK we found 25 and 11 species on the east and west side, respectively. Richness tended to be higher on VQS with an average of 28 ± 3.0 vascular plants species in the

plots. Not surprisingly, we did find more species in the larger plots than the 1 m² quadrats (Table 5). In the quadrats, mean richness and cover were consistent between 2009 and 2010 (Table 5). One exception was on VQS where plots in 2009 had higher vascular richness (21 ± 1.1 species) than in 2010 (17 ± 0.5 species). Overall, we found 1m² plots had a high plant cover and low cover of nonnative and tree or shrub species. Bare ground cover averaged only $7 \pm 0.9\%$ across all plots and is indicative of disturbance from frost heave or animals.

Table 4. Number of species present in the summit area sections of three alpine sentinel sites within the target region of ROMO as measured in 2009 and 2010.

Summit Area	JSM		VQS		PIK	
Section	2009	2010	2009	2010	2009	2010
E05	38	36	41	41	38	41
E10	37	-	30	41	30	45
N05	42	42	48	45	44	41
N10	43	-	43	43	36	30
S05	36	29	34	38	48	43
S10	51	42	42	47	34	41
W05	16	23	39	36	33	31
W10	20	-	34	39	15	24

Table 5. The mean cover of vascular plants, rock, bare ground and non-native species, the mean vascular species richness, and the mean shrub and tree richness found in 1m² quadrats in four alpine sentinel sites in 2010 and 2009..

	Number of plots	Mean vascular plant cover (%)	Mean solid rock cover (%)	Mean bare ground (%)	Mean vascular plant species richness	Mean non-native plant cover (%)	Mean shrub/tree species richness
GLA 2009	8	31 (6.5)	51 (6.8)	3 (1.4)	15 (1.3)	0	0
GLA 2010	-	-	-	-	-	-	-
PIK 2009	7	48 (6.2)	15 (4.8)	4 (0.9)	16 (2.2)	0	0
PIK 2010	16	48 (3.6)	16 (2.7)	6 (1.2)	14 (1.0)	0	0
VQS 2009	8	50 (5.5)	14 (3.8)	6 (2.2)	21 (1.1)	0	0
VQS 2010	16	58 (3.5)	17 (2.8)	6 (1.7)	17 (0.5)	0	0
JSM 2009	8	55 (5.3)	19 (3.3)	11 (4.6)	17 (1.1)	0.1 (0.06)	8 (3.4)
JSM 2010	16	55 (2.9)	17 (2.6)	13 (2.7)	16 (1.1)	0.1 (0.06)	9 (2.7)
ALL	79	51 (1.8)	20 (1.7)	7 (0.9)	17 (0.5)	0.02 (0.014)	3 (0.8)

Table 6. Soil properties at the four alpine summits in Rocky Mountain National Park. Values represent means and standard errors are in parentheses, n=4 for summit values and n=16 for the mean of all summits.

Peak	pH	NH ₄ (mg/kg)	NO ₃ (mg/kg)	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	SO (mg/kg)	CEC (meq/ 100g)	Total N (%)	Total C (%)	C:N	Organic Matter (%)	Sand (%)
GLA	4.9 (0.10)	10.1 (2.77)	4.6 (1.28)	0.26 (0.01)	274 (35.9)	1138 (142.5)	172 (25.6)	33 (2.0)	8.3 (0.97)	0.75 (0.24)	7.12 (2.33)	9.9 (0.77)	14.6 (6.05)	66 (4.6)
PIK	4.7 (0.12)	9.4 (1.55)	13.6 (2.99)	0.36 (0.08)	295 (29.3)	926 (253.7)	175 (41.5)	31 (1.4)	7.3 (1.68)	0.38 (0.08)	4.19 (0.92)	11 (0.13)	8.9 (1.34)	71 (1.0)
VQS	5.5 (0.24)	10.4 (1.19)	3.2 (0.62)	0.41 (0.08)	265 (19.3)	2460 (734.5)	244 (59.2)	35 (0.2)	15.4 (4.21)	0.94 (0.17)	10.90 (2.14)	11.5 (0.22)	24 (5.22)	68 (3.2)
JSM	4.8 (0.08)	9.7 (0.7)	5.7 (0.48)	0.23 (0.04)	249 (14.7)	719 (162.4)	134 (23.8)	31 (1.1)	5.8 (0.95)	0.37 (0.07)	4.19 (0.84)	11.2 (0.41)	8.9 (1.37)	70 (2.9)
ALL	4.9 (0.10)	9.9 (0.78)	6.8 (1.29)	0.31 (0.03)	270 (12.5)	1311 (251.7)	181 (20.7)	33 (0.72)	9.2 (1.42)	0.61 (0.09)	6.60 (1.04)	10.9 (0.26)	14.1 (2.43)	69 (1.5)

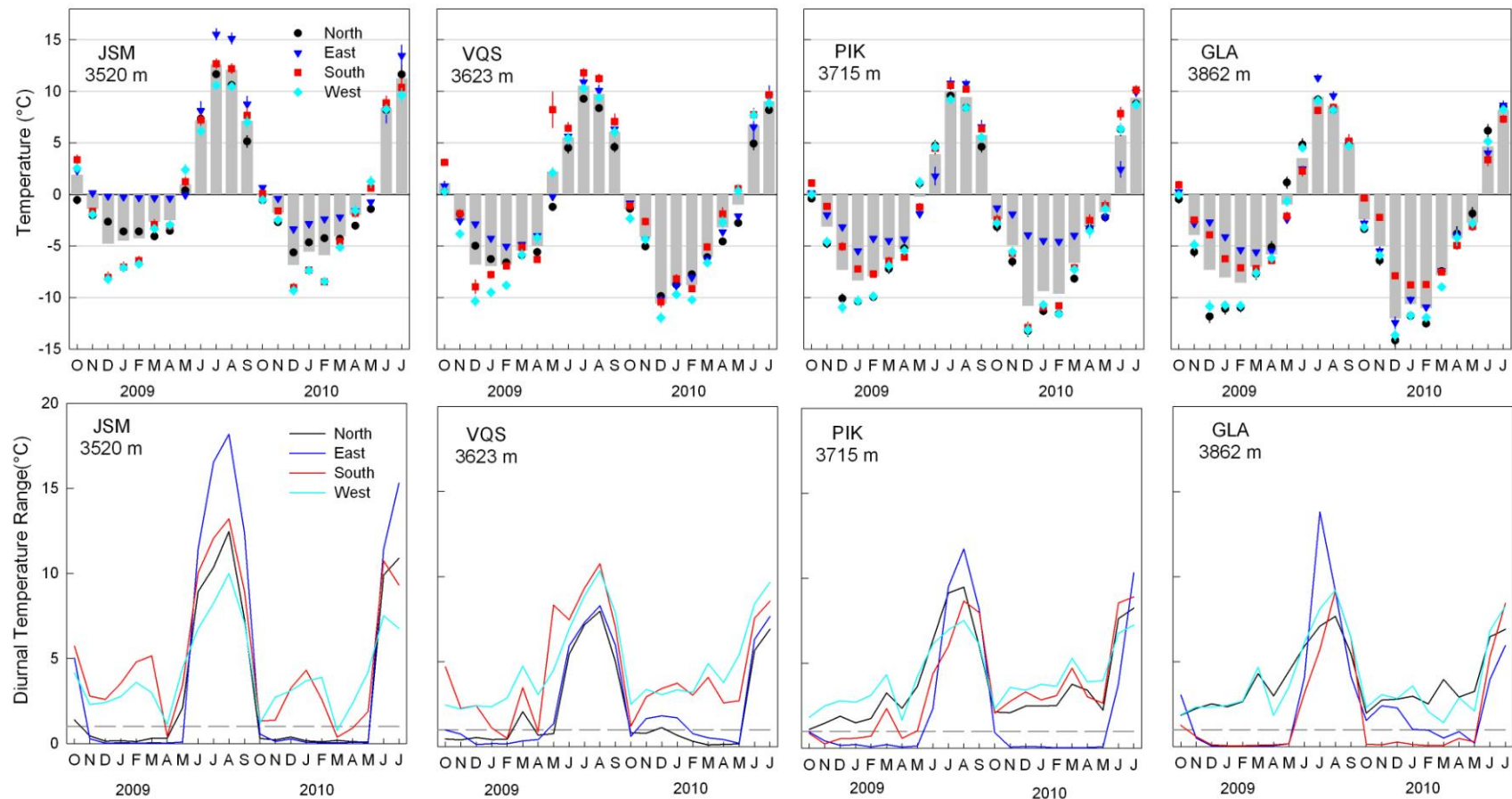


Figure 3. Mean monthly soil temperature on the GLORIA peaks at Rocky Mountain National Park from October 2008- July 2010 (top panel, gray bars) and mean monthly soil temperature on the east, south, and west sides of each peak (top panel, colored symbols). Bottom panel shows the diurnal temperature range on all peaks and all aspects from October 2008- July 2010.

Soil Chemistry

Soils from the GLORIA peaks were typically described as sandy clay loam in texture with a mean pH of 4.9 ± 0.1 (Table 6). Based on a multivariate ANOVA, we found no significant difference in soil chemistry among summits (Pillai's Trace=2.58, $P=0.24$) or across aspect (Pillai's Trace=2.52, $P=0.35$).

Temperature

Mean soil temperature decreased with elevation and was lowest at the highest summit GLA (Figure 4). At the higher two summits, PIK and GLA, mean monthly temperatures were above 0°C for only four months of the year: June, July, August, and September. Mean temperature in May was just above freezing on the lower peaks. For most peaks, the west aspect tended to be the coolest and the largest diurnal variations were seen on the east aspects. Diurnal temperatures ranged about 5°C during the fall, winter, and spring but closer to 10°C in the summer months. The diurnal temperature range of less than 1°C on some aspects of each summit during the winter months is suggestive of an insulating snow cover (e.g. the north and east side of JSM and the south and east side of GLA in Figure 4).

The growing season in 2009 (as defined by daily average minimum temperatures below or above 0°C) was about 1 week longer at the lowest peak than the highest peak. The first days of above freezing temperatures were about 1 week later in 2010 than 2009.

Table 7. First day of Fall and Spring on GLORIA summits as defined by average minimum temperatures below or above 0°C.

	JSM	VQS	PIK	GLA
2008 fall	Oct- 7	Oct-14	Oct-14	Oct-7
2009 spring	May-15	May-17	May-21	May-21
2009 fall	Oct- 1	Oct-1	Sep-23	Oct-1
2010 spring	May-26	May-26	May-30	May-31

Discussion

The goal of our alpine sentinel monitoring efforts in ROMO is to determine the status and trend in five parameters: vegetation composition and structure, invasive/exotic cover, soil condition, disturbance, and soil temperature. As of 2010, we have completed the second full season of field work and while we have increased our understanding of the status of the alpine at the four sentinel sites, we cannot yet describe trends. Moreover, our sampling was conducted at only the four sentinel sites limiting our ability to make park-wide inferences on the status of the alpine. Below, we summarize the results from above and highlight some of the most interesting aspects of the alpine monitoring program.

Vegetation Composition and Structure

We found between 63-71 species of vascular plants on the four summits. The lowest summit is smaller in area than the other three summits and has a higher diversity per area. We will need to be cautious with interpreting changes we see across summit sections from year to year because they may be caused by slight changes in the boundary lines rather than real changes in the flora. However, such variation does not affect the species diversity in the summit (the total across all summit sections) or target region. We found 8 new species in 2010 that were not recorded in 2009. Graminoids have been particularly hard to identify because not all are flowering at the time of our sampling. In 2010, we were able to spend more time collecting and identifying sedges and grasses. This increased effort allowed us to better distinguish species that had been lumped in 2009. We recommend that the species lists in 2010 should be considered the ‘best’ initial sample for these summits.

Despite the difficulty in identifying graminoids and the increased efforts in 2010, data from the 1m² quadrats was remarkably consistent across years. In the fall of 2010, the GLORIA working group identified summit area surveys and cover in the 1m² plots as the highest priority samples. Summit surveys provide the best estimate of diversity and 1m² plots are generally the most repeatable estimates of cover. In future efforts, we will continue to prioritize these plots. The optional method of 100 m² plots took about 2 hours per plot for 2 researchers. In areas with low plant diversity (typically the rocky western slopes), 1 m² plots sufficiently estimated diversity and cover. However, 100 m² plots did increase our detection of species in more heterogeneous areas with high vascular plant cover. On average we found 3 times more species in the summit surveys. In the future, we will repeat the 100m² plots when time allows but they will be a lower priority than the small quadrats.

The mean C score of the native vascular plants across summits was 7.1 ± 0.19 with the higher summits tending to have higher C scores (Table 3). Based on these scores, the plant community on the four sentinel sites is of high conservation value and typical of a fairly pristine sites. This is consistent with data we collected in 2009 suggesting that these sites show no evidence of human disturbance (Ashton et al. 2010a). In 2009 and 2010, we found only one exotic species in ROMO at the lowest alpine sentinel sites and no exotics at the sites at higher elevation. In addition to the upward migration of species, climate change may allow for the spread of exotic/invasive species into the alpine where they are typically limited by the harsh environment (Pauchard et al. 2009). *Taraxacum officinale*, or common dandelion, the exotic present at the lower sites (less than 1% cover), originated in Eurasia and is considered naturalized throughout

the United States. It is one of the few exotics that is found in the alpine and has also been found in GLAC and GRSA GLORIA sentinel sites.

Soil Chemistry

The four summits in the GLORIA target region at ROMO were chosen to have similar geology and climate. It is therefore not surprising that soil chemistry and texture soils were also consistent across the summits. A recent study of alpine soils around the Indian Peaks and ROMO, found similar levels of many of the soil constituents that we measured (Liptzin and Seastedt 2010). Interestingly, Liptzin and Seastedt (2010) found patterns in C:N ratios in soil that varied by the side of the continental divide and by aspect and speculated that the variation was driven by patterns of nitrogen deposition. While the GLORIA sites lie on or west of the divide, the average soil C:N was fairly low, 10.9 ± 0.25 , and is more representative of the values reported from the east side of the divide (10.9 ± 0.6). This may suggest that nitrogen deposition in this area is also similar to the east side.

Temperature

The alpine at ROMO is characterized by extremely cold temperatures and a short growing season (Figure 4). Temperatures generally decreased with increasing elevation, and therefore the highest peak, GLA recorded the lowest average temperatures. The variation in vegetation across aspects, field observation, and the temperature record suggests that the west side is consistently the coldest aspect of the peaks. When the sites were established, we assumed they were all in the same climate region (a prerequisite of a GLORIA target region). The broad scale patterns in the temperature data suggest that this is the case. For instance, December 2010 was a particularly cold month on all peaks (Figure 4). Future analyses are needed to derive an index based on soil temperature that can be used to estimate the length of the snow cover season on all peaks. Over time, the temperature records collected at these sites will greatly add to our understanding and documentation of climate change in the alpine at ROMO.

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Appendix 1: US-RMN 2010 Field Log

Date	Peak	Persons	Activities	Notes
7/4/2010	JSM	Isabel Ashton, James Chowanski, Kurt Chowanski	Retrieve and replace dataloggers; photos missing in 2009. Put logger on HSP.	1.75 hours hike from Lake Irene trailhead; crossed back to Mt. Ida trail and down to Milner Pass (3 hours to return).
7/11/2010		Isabel Ashton, Kyle Motley	Picked up WRD vehicle in Fort Collins	Extended cab pickup
7/12/2010	VQS	Isabel Ashton, James Chowanski, Kurt Chowanski, Katharine Driver, Kyle Motley	Training; 1 frequency and cover plot; 100 m ² plot; replaced dataloggers; setup SAS	Left Milner pass 9; on VQS by 10; left at 2pm.
7/13/2010	VQS	Isabel Ashton, James Chowanski, Kurt Chowanski, Katharine Driver, Kyle Motley	VQS: Finished 1 100m ² plot; 4 cover plots; 3 SAS	Start work on VQS by 9.
7/14/2010	VQS	Isabel Ashton, James Chowanski, Kurt Chowanski, Katharine Driver, Kyle Motley	VQS: SASs	Left Milner pass 7:30; on VQS by 8:30.
7/15/2010	VQS	Kyle Motley, Katharine Driver	VQS: 2.5 – 100m ² plots	Kyle injured and could no longer hike after this trip.
7/16/2010	VQS	Isabel Ashton, James Chowanski, Katharine Driver	VQS: 0.5 – 100m ² plot ; Cover plots	
7/19/2010	PIK	Isabel Ashton, James Chowanski, Kurt Chowanski, Katharine Driver, Paul McLaughlin	PIK: found plots, replaced 3 loggers; 4 cover plots; 1 100m ² plot	Left Milner Pass 7:45 hoped to go to GLA but horrible weather made for a short day. Back to car by 1:30.
7/20/2010	JSM	Isabel Ashton, James Chowanski, Kurt Chowanski, Katharine Driver, Brittany Thompson, Laura O'Gan	JSM 4 5 m SAS; 1 10mSAS; logger at HSP; 16 cover plots; plant photographs	Left Lake Irene at 8. On JSM at 9:45.
7/21/2010		OFF		
7/22/2010	PIK, GLA	Isabel Ashton, James Chowanski, Kurt Chowanski, Katharine Driver, Brittany Thompson	PIK: 4- 5m SAS; 5 cover plots; East logger GLA: replaced loggers. Put logger on HSP	Arrived 9:30 on PIK. Katie and Kurt retrieved and replaced dataloggers from GLA; put logger on HSP. Isabel and Brittany on PIK: Storm chased us off at 1:30. GLA needs new nails and cuffs.
7/23/2010	PIK	Isabel Ashton, James Chowanski, Katharine Driver, Brittany Thompson	PIK: 1-100 m ² plot; 4- 10m SAS; 7-cover plots. Returned vehicle to Fort Collins	Arrived 9:30 on PIK. Left at 1pm

Appendix 2: US-RMN species list from 2010 summit surveys

Species	JSM 5m	VQS 5m	VQS 10m	PIK 5m	PIK 10m
<i>Achillea millefolium</i> L. var. <i>occidentalis</i> DC.	X	X			
<i>Agoseris aurantiaca</i> (Hook.) Greene	X			X	
<i>Agoseris glauca</i> (Pursh) Raf. var. <i>agrestis</i> (Osterh.) Q. Jones ex Cronquist					
<i>Androsace septentrionalis</i> L.	X	X		X	X
<i>Anemone narcissiflora</i> L. var. <i>zephyra</i> (A. Nelson) Dutton & Keener			X		
<i>Antennaria media</i> Greene	X		X		X
<i>Arabis drummondii</i> Gray	X				
<i>Arenaria fendleri</i> A. Gray var. <i>fendleri</i>	X	X		X	X
<i>Arnica rydbergii</i> Greene	X		X		
<i>Artemisia arctica</i> Less. subsp. <i>arctica</i>	X	X		X	X
<i>Artemisia scopulorum</i> Gray		X	X	X	X
<i>Athyrium alpestre</i> (Hoppe) Milde var. <i>americanum</i> Butters			X		
<i>Besseyia alpina</i> (Gray) Rydb.				X	
<i>Calamagrostis purpurascens</i> R. Br.	X	X		X	X
<i>Campanula rotundifolia</i> L.		X	X		
<i>Campanula uniflora</i> L.		X	X		X
<i>Carex arapahoensis</i> Clokey	X		X		
<i>Carex heteroneura</i> W. Boott var. <i>chalciolepis</i> (Holm) F.J. Herm.				X	X
<i>Carex microptera</i> Mack.		X			
<i>Carex pyrenaica</i> Wahlenb. subsp. <i>pyrenaica</i>	X		X	X	X
<i>Carex rossii</i> Boott	X				
<i>Carex rupestris</i> All. var. <i>drummondiana</i> (Dewey) Bailey	X	X		X	X
<i>Carex scopulorum</i> T. Holm			X		X
<i>Castilleja occidentalis</i> Torr.		X		X	X
<i>Castilleja puberula</i> Rydb.			X		
<i>Cerastium arvense</i> L. subsp. <i>strictum</i> Gaudin		X		X	
<i>Chamerion angustifolium</i> (L.) Holub subsp. <i>circumvagum</i> (Mosquin) Hoch			X		
<i>Chionophila jamesii</i> Benth.					X
<i>Cirsium scopulorum</i> (Greene) Cockerell ex Daniels			X		
<i>Claytonia megarhiza</i> (Gray) Parry ex S. Wats.				X	X
<i>Danthonia intermedia</i> Vasey	X	X	X	X	
<i>Draba aurea</i> Vahl ex Hornem.		X		X	
<i>Draba breweri</i> S. Watson var. <i>cana</i> (Rydb.) Rollins		X			
<i>Draba streptocarpa</i> A. Gray	X	X	X	X	X
<i>Dryas octopetala</i> L. subsp. <i>hookeriana</i> (Juz.) Hultén			X		
<i>Elymus scribneri</i> (Vasey) M.E. Jones	X	X	X	X	
<i>Erigeron melanocephalus</i> (A. Nelson) A. Nelson			X		X
<i>Eritrichium nanum</i> (L.) Schrad. ex Gaudin var. <i>aretioides</i> (Cham.) Herder		X		X	X
<i>Erigeron peregrinus</i> (Banks ex Pursh) Greene subsp. <i>callianthemus</i> (Greene) Cronquist			X		
<i>Erigeron pinnatisectus</i> (Gray) A. Nels.	X	X		X	X
<i>Erigeron simplex</i> Greene	X	X	X	X	X

Species	JSM 5m	VQS 5m	VQS 10m	PIK 5m	PIK 10m
<i>Erysimum capitatum</i> (Dougl. ex Hook.) Greene		X	X	X	X
<i>Festuca baffinensis</i> Polunin			X		
<i>Festuca brachyphylla</i> Schult.	X	X		X	X
<i>Gentiana algida</i> Pall.			X		
<i>Gentiana prostrata</i> Haenke			X		
<i>Geum rossii</i> (R. Br.) Ser. var. <i>turbinatum</i> (Rydb.) C.L. Hitchc.		X		X	X
<i>Helictotrichon mortonianum</i> (Scribn.) Henr.	X	X	X		
<i>Heterotheca pumila</i> (Greene) Semple		X	X		
<i>Heuchera parvifolia</i> Nutt. ex Torr. & Gray				X	
<i>Hieracium gracile</i> Hook. var. <i>gracile</i>			X		
<i>Juncus drummondii</i> E. Mey.	X				
<i>Kobresia myosuroides</i> (Vill.) Fiori		X		X	X
<i>Lewisia pygmaea</i> (Gray) B.L. Robins.	X		X	X	X
<i>Lloydia serotina</i> (L.) Rchb.		X		X	X
<i>Luzula spicata</i> (L.) DC.	X	X	X	X	X
<i>Mertensia lanceolata</i> (Pursh) DC.	X	X	X	X	X
<i>Minuartia obtusiloba</i> (Rydb.) House	X	X	X	X	X
<i>Minuartia rubella</i> (Wahlenb.) Hiern	X	X	X		
Compositae in US-RMN			X		
<i>Oreoxis alpina</i> (Gray) Coult. & Rose	X	X		X	X
<i>Oxyria digyna</i> (L.) Hill			X		
<i>Paronychia pulvinata</i> A. Gray	X	X		X	X
<i>Penstemon whippleanus</i> Gray	X		X		
<i>Picea engelmannii</i> Parry ex Engelm.	X				
<i>Poa alpina</i> L.		X			
<i>Poa arctica</i> R.Br.	X	X	X	X	X
<i>Poa glauca</i> Vahl subsp. <i>rupicola</i> (Nash ex Rydb.) W.A. Weber	X	X	X	X	X
<i>Polygonum bistortoides</i> Pursh	X	X	X	X	X
<i>Polemonium viscosum</i> Nutt.		X	X	X	X
<i>Polygonum viviparum</i> L.			X		
<i>Potentilla diversifolia</i> Lehm.	X	X	X	X	
<i>Potentilla ovina</i> Macoun	X	X	X		
<i>Potentilla subjuga</i> Rydb.	X	X	X	X	
<i>Primula angustifolia</i> Torr.		X	X	X	X
<i>Ranunculus adoneus</i> A. Gray	X	X	X	X	X
<i>Ranunculus eschscholtzii</i> Schlecht.		X			
<i>Rhodiola integrifolia</i> Raf.			X		
<i>Ribes montigenum</i> McClatchie			X		
<i>Salix brachycarpa</i> Nutt.				X	
<i>Salix petrophila</i> Rydb.	X			X	X
<i>Saxifraga chrysantha</i> Gray		X			
<i>Saxifraga flagellaris</i> Willd. ex Sternb.		X	X		
<i>Saxifraga rhomboidea</i> Greene	X		X	X	X
<i>Sedum lanceolatum</i> Torr.	X	X	X	X	X
<i>Selaginella densa</i> Rydb.	X	X	X	X	X
<i>Senecio fremontii</i> Torr. & A. Gray var. <i>blitoides</i> (Greene) Cronquist			X		

Species	JSM 5m	VQS 5m	VQS 10m	PIK 5m	PIK 10m
<i>Senecio soldanella</i> Gray					X
<i>Sibbaldia procumbens</i> L.	X	X		X	X
<i>Silene acaulis</i> (L.) Jacq. var. <i>subacaulescens</i> (F.N. Williams) Fern. & St. John		X		X	X
<i>Solidago multiradiata</i> Ait.	X	X	X		X
<i>Stellaria longipes</i> Goldie		X	X		
<i>Stellaria umbellata</i> Turcz. ex Kar. & Kir.			X		
<i>Taraxacum officinale</i> Weber	X	X			
<i>Tetraneuris acaulis</i> (Pursh) Greene var. <i>caespitosa</i> A. Nelson			X		
<i>Tetraneuris grandiflora</i> (Torr. & Gray ex Gray) Parker		X		X	X
<i>Thalictrum alpinum</i> L.			X		
<i>Thlaspi montanum</i> L. var. <i>montanum</i>	X	X	X	X	X
<i>Tonestus lyallii</i> (Gray) A. Nels.			X	X	X
<i>Tonestus pygmaeus</i> (Torr. & Gray) A. Nels.	X	X		X	X
<i>Trifolium dasyphyllum</i> Torr. & Gray	X	X	X	X	X
<i>Trifolium nanum</i> Torr.		X	X	X	X
<i>Trifolium parryi</i> A. Gray	X	X	X	X	X
<i>Trisetum spicatum</i> (L.) K.Richt.	X	X	X	X	X
<i>Vaccinium scoparium</i> Leiberg ex Coville	X		X		X